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# Calculation of proton radioactivity half-lives

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**Abstract**

We have investigated the proton radioactivity half-lives of 45 proton emitters within the framework of the Wentzel–Kramers–Brillouin (WKB) method by considering the Bohr–Sommerfeld quantization condition. The orientation angle dependent Woods–Saxon, Coulomb, and spin–orbit potentials and centrifugal potential have been used in calculations. We observed that using the orientation angle dependent formalism decreases the values of calculated half-lives.


*Keywords:* WKB; Proton radioactivity; Quantization

## 1. Introduction

The proton drip-line is a unique area for investigating the physical states of protons in nuclei. After discovery of the proton emission from the isomeric states [1,2] and later the ground state proton emission [3–5] a lot of efforts have been made and by now about 45 nuclei [6] are known that emit proton from their ground states and isomeric states. Some of the most popular theoretical methods [7–9] that are used in proton-decay studies can be grouped into three categories: i) WKB based methods [10–21]. Which are in close analogy to the alpha decay mechanism proposed independently by Gamow [22] and by Condon and Gurney [23]. ii) Wave function matching methods. These methods are based on matching the wave function of single protons inside the nucleus with the outgoing Coulomb wave function of the proton outside the nucleus [24–33]. iii) Fragmentation based approaches and fission like methods [34–36].

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WKB based methods are in common between the alpha-decay and proton-decay models. In this frame work the most important differences between these two decay modes are: the interaction between the radiated particles and the daughter nucleus and the formation factor of the exiting particle which in the case of proton-decay is the spectroscopic factor. The spectroscopic factor can be calculated using the relativistic mean field model [37,38] or BCS model [39–43].

An essential part of the WKB calculations which makes them self consistent is the Bohr–Sommerfeld quantization condition [44]. Orientation angle dependent potentials have been widely used in the alpha-decay [45–52], proton decay [24,25,28,29,53], and heavy ion reaction [54–56] studies. In Ref. [49] has been proposed a method which can be used in order to apply the Bohr–Sommerfeld quantization condition to the case of alpha emitters. Ref. [57] has used this method in the case of cluster decay and in this paper we will use the same method in order to calculate the half lives of some proton emitters. In this method the normal nuclear potential should be multiplied by an extra angle dependent coefficient which is determined using the quantization condition at each angle. Recently, Santhosh and Sukumaran [53] have applied the Coulomb and proximity potential model for deformed nuclei (CPPMDN) to proton radioactivity by taking into account the deformation of parent and daughter nuclei.

In the first section we summarize the theory of the proton decay based on tunneling model. The numerical results and discussions are presented in the second section and finally the conclusions will be expressed.

## 2. Model

### 2.1. Potential

The potential energy that a single proton feels in a spherical nucleus can be estimated using mean field potentials such as the real part of an optical model potential [58,12]:

$$
\begin{aligned}
&V = V_N + V_{Spin-Orbit} + V_{Coul} + V_L \\
&V_N = -V_R f(r, R_R, a_R) \\
&V_R = [54.0 - 0.32E_P + 0.4\frac{Z}{A^{\frac{1}{3}}} + 24.0\frac{(N-Z)}{A}] \ \text{MeV} \\
&f(r, R, a) = \frac{1}{[1 + e^{(r-R)/a}]} \\
&V_{Spin-Orbit} = V_{SO} \vec{\sigma} \cdot \vec{L} \lambda_\pi^2 \frac{1}{r}\frac{d}{dr} f(r, R_{SO}, a_{SO}) \\
&\vec{\sigma} \cdot \vec{L} = L, \quad (j = L + \frac{1}{2}) \\
&\vec{\sigma} \cdot \vec{L} = -(L+1), \quad (j = L - \frac{1}{2} > 0) \\
&V_{Coul} = (Ze^2/8\pi\epsilon_0 R_c)[3 - r^2/R_c^2], \quad (r \le R_c) \\
&V_{Coul} = Ze^2/4\pi\epsilon_0 r, \quad (r > R_c) \\
&V_L = L(L+1)\frac{\hbar^2}{2mr^2}
\end{aligned}
\tag{1}
$$

in which $Z$, $N$ and $A$ are the charge, the neutron number and the mass number of the daughter nucleus respectively. The constants have the following values [12]: $R_R = 1.17A^{1/3}$, $a_R = 0.75$,

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